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ENGINEERING & GINNING

Gin Process Control

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ABSTRACT

Automation provides key benefits to production plants: increased speed of production, improved quality control, enhanced worker safety, and reduced production costs. Numerous types of systems use automated control throughout the world; in cotton gins, there are a few main systems that rely on some form of control: material flow, fire suppression, dryer temperature, press operation, and moisture restoration systems. This chapter provides an overview of control systems in general along with key examples of control systems in use in U.S. cotton gins.

There are two basic categories of control systems: open loop and closed loop. An open-loop system lacks automatic feedback. A human assesses the performance of the system by reading sensors or watching the process. If necessary, manual controls are adjusted to send control signals to the output actuators. A simple example of an open-loop control system is a faucet. Once it has been turned on water flows at a continuous rate until someone intervenes—hopefully before the tub overflows! An example in a cotton gin is the seed cotton dryer. In an older, open-loop seed cotton drying system, the ginner sets the temperature not the moisture content of the cotton (which is the desired objective). A schematic flow diagram of this type of open-loop control is presented in Fig. 1. In this type of open-loop system the system cannot adjust itself to achieve the desired objective of providing cotton at a certain moisture content.

The other type of control system is a closed loop. In a closed-loop control system a computer (or float valve, smart switch, or thermostat) controls the output. A simple example of a closed-loop control system is an oven. The cook adjusts the thermostat manually to the desired temperature and once the temperature is set, the thermostat in the oven automatically adjusts how much gas flows to the heating element to maintain that temperature. An example in a cotton gin is the tramper on the bale press, illustrated in Fig. 2. The programmable logic controller (PLC) turns on the motor to the tramper shuttle and then monitors the limit switch at the far end of the shuttle's travel. Once the shuttle breaks the far-side limit switch, the PLC shuts off the motor and sets an internal memory flag to indicate the shuttle is in position to travel back to the home starting position.

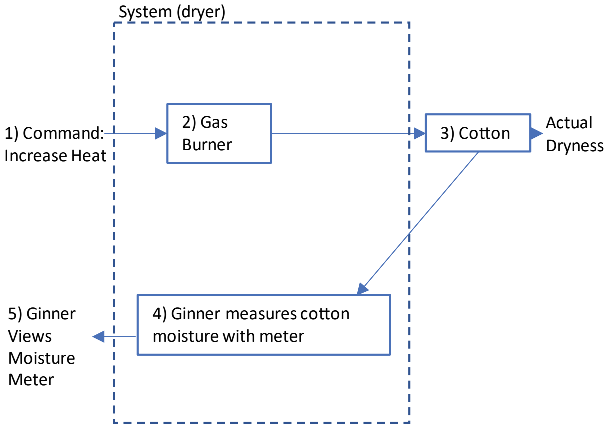

Figure 1. Open-loop control of a seed cotton dryer where the ginner adjusts the gas flow while manually monitoring the pick-up point air temperature inside the drier. As the objective is to maintain the cotton moisture within an acceptable range, this is a crude method by which to control moisture content of cotton.

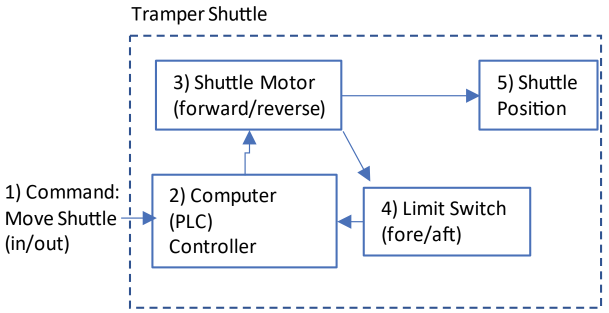

Figure 2. Simple closed-loop control of a tramper shuttle where the programmable logic controller (PLC) turns on the shuttle motor and monitors the limit switch at the far end of the travel. When the limit switch trips, the PLC shuts off the motor and sets a memory flag to indicate that the shuttle position is at the far side of travel. The next time the switch activated, the PLC knows to run the motor in reverse and monitor the near-side limit switch.

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In modern processing plants, automation (closed-loop control) plays a vital role in ensuring timely, cost-effective production with the additional goal of providing a high yield of products with a level of quality that is sufficient for the target market. The discipline that allows for this automation has been coined "control theory", which is the mathematical discipline that provides optimal computer algorithms that can be used to run a process in a hands-off manner, free from human intervention. Examples of control systems from modern cotton gins follow the descriptions of the parts and functions of a control system.

CONTROL SYSTEMS OVERVIEW

A control system is any system that takes as an input a desired objective and then continuously tracks and adjusts the current system state to achieve that objective. This tracking and automatic adjustment is termed "automated control". There are several key advantages that are achieved by utilizing this type of automated control: (1) reduction of errors by automatically adjusting a system's set-points to achieve the desired objective that was programmed into the system; (2) improvement of the stability of an unstable system; (3) reaction and response to sudden changes in input conditions and external disturbances; and (4) production of a reliable and repeatable product at minimal cost with minimal down-time. Typical control systems are comprised of several key elements.

PLC. The process controller (computer) is programmed to read the inputs (control variables); calculate a response based upon the inputs; then in comparison to the desired output state, calculate an appropriate action, and send the desired control response signal to the corresponding output actuator.

Inputs. Process states such as position, temperature, speed, and flow are known as input variables.

Output. The objective that is being controlled such as temperature, position, velocity, or flow (known as output variables).

Feedback. The process of using, or feeding back, the measured outputs to allow the PLC to compute the error from the desired command output and send an appropriate response signal to the driven actuator (e.g., gas flow input to a dryer or water temperature for moisture restoration).

Error. The difference between the desired output and the currently measured output.

Control Loop. The loop cycle of measuring the output, computing the output error, and crafting the desired control signal that will then be sent to the output actuator followed by the actual response of the output.

Actuators. Devices that take an input control signal and translate that signal into an energy input into the system to affect a change in the output. Examples are (a) hydraulic solenoids that turn on/off hydraulic flow to hydraulic cylinders (thereby affecting a change in position of a part of a machine); (b) gas flow values that adjust the flow of natural or propane gas, thereby increasing or decreasing the amount of heat added to an air stream; and (c) variable-frequency drives that take an input signal and use it to adjust the voltage and frequency of the three-phase electrical power to a motor, thereby affecting the speed and torque output of the motor.

Communication Channels. The underlying physical connection and electrical interface (BUS) from the PLC to the actuator. Examples of communication channels are: RS485 serial, ethernet, CAN-Bus, and Profi-Bus.

Communication Protocol. The software data structure that specifies the data organization so software can be written to communicate with devices supporting the standard. Examples are: TCP/IP, UDP, and ModBus, all of which are commonly used protocols found in process control environments.

Control Signal. The message from the controlling process computer, such as a PLC, to the actuator. Typical signals include voltage, current (4 to 20 milliamps), or digital communication messages (e.g., serial data over RS232 or RS484 communication channels).

Automated Feedback Control. The description of the computer used for control, typically a PLC, that automatically reads the input signals and uses a computer algorithm to compute a response and sends it immediately to the actuator. A well-designed system can maintain a desired output state without intervention from a human operator.

State. The description of both measured and unmeasured physical attributes of the system. Examples are: (a) temperature in a tower dryer; (b) position or velocity of an actuator; (c) rotational velocity (RPM) of a motor, shaft, or saw; (d) position of a switch or dial; and (e) flow of a fluid (hydraulic, gas, or air).

CONTROL SYSTEM PARTS

Input Elements. These are utilized in a feedback control system to provide information on how the system is currently performing and where its operating states are currently working.

Sensors. Devices that read system states and provide information back to the computer control systems (PLC), and in some cases, the human operator. Many types of sensors are readily available to sense or read: (1) temperature, (2) flow, (3) position or displacement, (4) pressure, (5) dial position, (6) density, (7) moisture content, and (8) presence of fire.

Switches. A common input sensor that is either on or off. Example uses of switches are: (1) to indicate to the PLC a desired state (such as indicate if power is on to the gin stand), and (2) to provide an indication that a hydraulic cylinder is at the limit of its extension (travel). Typically used to park a machine element at a home or resting position.

Output Elements. *Actuators.* These include (1) linear actuators that impart a translational movement along a single direction. Typically, this is achieved through hydraulic or pneumatic cylinders. (2) Rotary actuators that impart rotational motion to an object. Typically, this is done with an electric or hydraulic motor. Examples used in cotton gins are the electric motors powering gin stands and pneumatic conveyance fans or turning the press box. (3) Valve actuators that control the flow of fluids such as air or hydraulic fluid. Examples of their usage are: (a) gas valves that control how much combustible gas is allowed to flow to burners, thereby controlling the temperature of the drying system; (b) hydraulic or pneumatic valves that control how much fluid flows into an actuating cylinder or motor, thereby imparting a velocity or change in position; and (c) material flow valves that direct material to the next processing machine or divert seed cotton or lint in the event a fire is detected.

Controllers. *Algorithms.* The mathematical recipes utilized by computers and controllers (that use microcomputers, such as PLCs). Some commonly practiced control algorithms are: (1) proportional (P) controller; this controller provides a simple linear response to the error to signal that is sent to the actuator. (2) Proportional-integral (PI) controller; this controller computes the actuator command signal from both a linear response to the error as well as a sum of the latest histories of the errors. (3) Proportional-integral-derivative (PID) controller; this algorithm tempers the PI response by also including a response due to how fast the error has been changing.

Computer Controllers. These include: (1) PLC, a specially designed system that incorporates a microcomputer that is easily programmed utilizing a simple programming language known as ladder logic. This type of controller is the main-stay of the process control world and has a rich history and wide support by industrial control manufacturers. (2) Language based controllers (software written in source code), although not as common as PLCs, these provide the ultimate flexibility in developing advanced control systems. This is the approach utilized in the development of most robots.

Human Observer-Controller (Open Loop). This type of control depends upon a human operator to manually adjust control switches and dials to achieve the desired processing objectives. This type of control is becoming less and less utilized because automatic control afforded by closed-loop systems can be more economical as it can allow for a human operator to control a more complex processing system and do so with a more consistent and higher level of quality of the output products.

EXAMPLES OF FEED-BACK CONTROL SYSTEMS USED IN MODERN COTTON GINS

Material Flow–Module Feeder Speed Control. The speed of the incoming cotton flow can be controlled optimally by coordinating the speed of the module feeder floor to maintain the level of seed cotton inside the steady flow (Fig. 3). The level of the seed cotton inside the steady flow can be provided to the PLC by setting up several optical through-beam sensors at various heights inside the steady flow. As cotton fills up inside the steady flow, the cotton breaks the optical beams starting from the bottom sensor and then progressively breaking the higher-level sensor beams as the hopper fills with seed cotton. These optical beam sensor signals are passed to the PLC so the PLC knows how full the hopper is. In the example in Fig. 3, the PLC can determine if the hopper is completely empty, half full, or completely full. For finer control, more optical beams can be added to the system. Another key sensor that improves the control is to bring in the gin stand kick-out sensors so the PLC can determine if the gin is utilizing all the gin stands and requires the full flow rate, or if it should down regulate the maximum flow rate due to one or more gin stands being off line. By combining the number of gins stands with the level of seed cotton inside the hopper, the PLC can determine the optimal speed to run the module feeder floor.

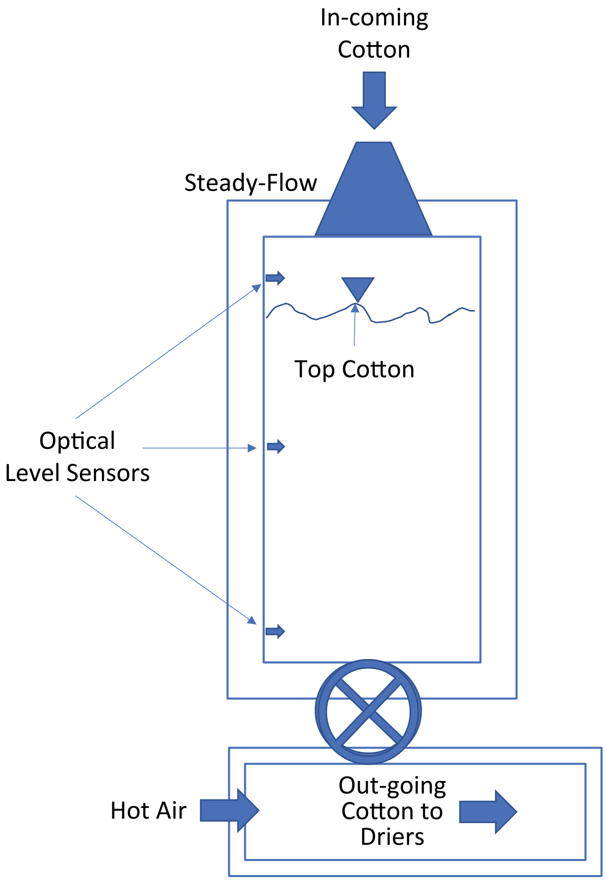

Figure 3. Schematic of a cotton steady-flow hopper with level sensing optical sensors to inform the PLC as to the state of cotton fill inside the hopper.

An example equation the PLC would use is:

$$\mathit{Speed\_ModuleFeederFloor} = \frac{\mathit{\#GinStandsOperational}}{\mathit{Total\ \#\ GinStands}}\,(100 - \%\ \mathit{Fill\_SteadyFlow})$$

When all the gin stands are operational and the steady flow is empty (all optical beams engaged) then the PLC will compute 100% module floor speed. Once the hopper becomes half full, it will slow down to 50%, and will shut off the module feeder floor motor once the hopper is completely full. Should any of the gin stands be off line during this process the module floor speed is further reduced to the fraction of operational gin stands divided by the total number of gin stands in the plant. This way the system gracefully down modulates the module feeder floor speed to compensate for the reduced capacity of the gin due to gin stands being off line. The control feed-back loop design schematic is detailed in Fig. 4.

Roller Gin Stand Automatic Control. Another example of controlling material flow is the automated control developed for roller gin stand feeders. Typical roller ginneries have more gin stands than one person can watch. Before automation ginners would set the speed of the feeder below the rate the gin stand was capable of to avoid having to clean out a choke up in the event of a sudden change in the system (e.g., a wet section in the module). Because computer controls can respond almost instantly, they allow the roller gin to operate at full capacity for the given conditions, maximizing production, and to change the feed rate the instant those conditions change, minimizing choke ups.

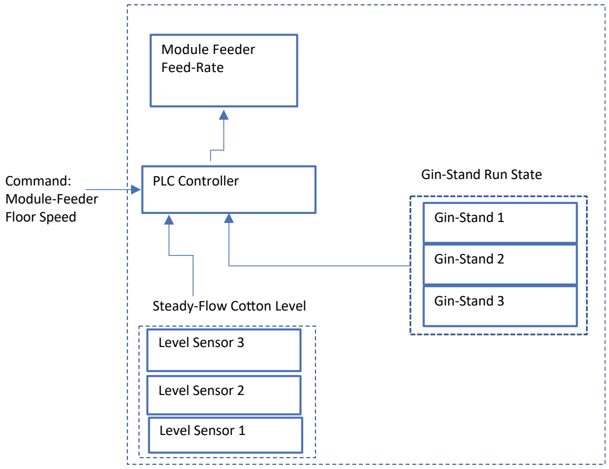

Figure 4. Feed-back control loop design for control of module feeder floor speed utilizing inputs from steady-flow seed cotton fill level and the number of operational gin stands; when the two inputs are combined, the PLC has sufficient information to optimally control the module feeder floor speed.

The gin stand computer control monitors and adjusts the seed cotton feed rate for a given rotary-knife power setpoint. Varying levels of moisture and trash in the seed cotton are automatically compensated for through their effect on rotary-knife power. This results in less downtime (no choke ups), less damage to the machinery, and getting the most production out of the gin stand. Many controls have been installed on conventional roller gin stands that gin one to 1.5 bales per hour per gin stand. With the adoption of high-speed roller ginning, the control is a necessity because these stands typically gin four to five bales per hour per gin stand and must be monitored closely.

One type of control used in commercial roller ginneries is a feedback control system that uses a PID controller. This is the same type of controller used on many burners. In addition to the controller, the roller gin stand control requires a separate 2.24-kW (3-hp) motor to drive the rotary knife (the rotary knife originally was driven off of the gin motor), a watt transducer, and a feed motor control.

Figure 5 is a flowchart of the roller gin stand automatic control. The process begins with the rotary knife motor sending a power signal to the watt transducer. The transducer converts the signal and sends it to the controller. The controller then sends a signal to the feed motor control that adjusts the speed of the feed rollers on the feeder. The process status (ginning) is monitored by the controller. When ginning stops, the controller automatically restarts the gin stand at a slower feed rate than it stopped at, and a choke up is avoided. The controller has alarms that stop the gin stand if the rotary knife motor is overloaded or turns on a light to alert the ginner that the gin stand is running too slow.

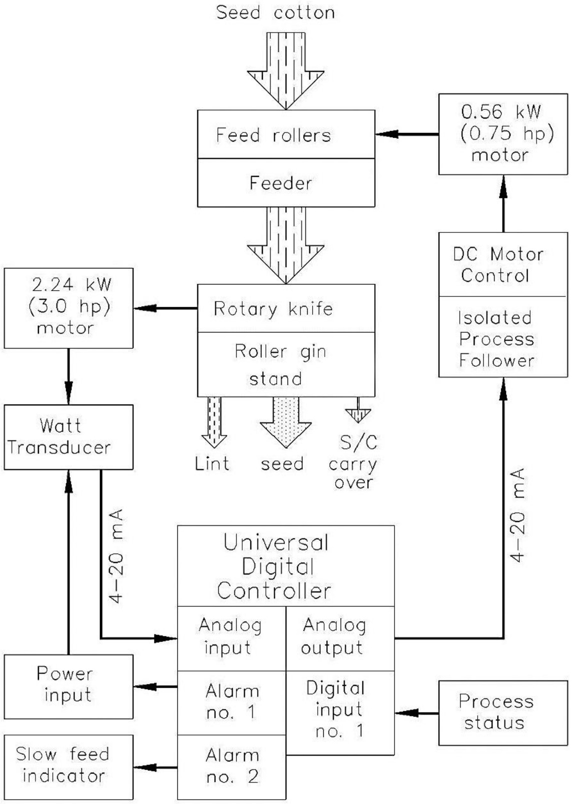

Figure 5. Roller gin stand automatic control loop that monitors and adjusts the seed cotton feed rate for varying levels of moisture and trash in the seed cotton.

This is an example of one type of control system used in roller ginneries that Gillum et al. (**1995**) described in detail. Other systems are more sophisticated. The control system used on the Lummus Series 2000 high-speed roller gin stand employs features such as monitoring the temperature of the ginning roller, variable speed drives on the roller and rotary knife, and operation via color touch screen. But all control systems have the same basic function to maximize processing rate and protect the roller gin stand.

Fire Suppression Systems. In many cotton gins spark detection technology is used to sense the presence of fire so that burning cotton can be diverted from the material flow path and gin personnel can extinguish the fire. A sophisticated sensor is used that can detect an ember as small as 2 mm (0.08 in) traveling as fast as 220 kph (136 mph). It initiates the controls process (diverting flow or releasing suppression agents, shutting down relevant production components, and signaling the incident) in less than 50 msec (Argus, 2020).

Seed Cotton Dryer Control. In many cotton gins moisture control is run as a predominant open-loop control system with an inner temperature control loop that is controlled via a PLC, based upon the ginners desired temperature setting (Fig. 6). An improved closed-loop control scheme can be achieved by adding a cotton moisture sensor that the PLC can use to close the loop control. When designing a closed-loop controller for moisture, it should be noted that the dryer BTU demand, to achieve target moisture content, is driven by both the moisture content of seed cotton as well as the mass flow of the seed cotton. It should also be recognized that for very wet cotton the maximum ginning rate is considerably reduced, thus the moisture content also drives the maximum module feeder floor speed. Hence it is not possible to separate out temperature control from module feeder floor speed control as they are both dependent upon the other. However, a suitable closed-loop design can be achieved by combing these operations into one large multi-input multi-output controller. One potential schematic of such a controller design is detailed in Fig. 7. In this approach, a sensor reads the out-going seed cotton moisture and alerts the PLC, which is also monitoring and controlling the module feeder floor speed. The two signals are combined in an algorithm to produce the appropriate control signals (BTU output for drier and module feeder floor speed).

For machine and process automation studies the closed-loop category is of interest as it is only by closing the loop with a computer that complete automation can be achieved. Further, it has been demonstrated repeatedly over the last several decades that by closing the loop, not only can labor costs be lowered, by improving product rates per man-hour, but also improvements in quality and repeatability are achieved.

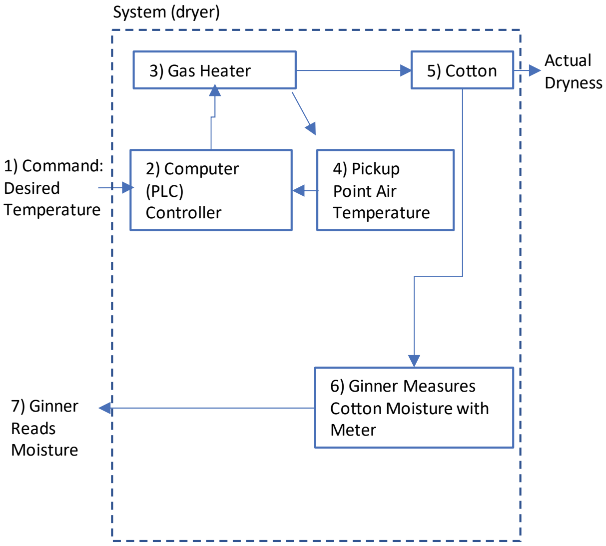

Figure 6. Open-loop control of a seed cotton dryer, for temperature, where the ginner sets the desired target temperature that is maintained by a PLC. The PLC controls the gas flow to maintain the target temperature; however, it is up to the ginner to manually monitor the cotton moisture and adjust the target temperature to keep the cotton moisture within an acceptable range. This control scheme is effectively an open-loop control of seed cotton moisture utilizing an inner automatic control loop for temperature control.

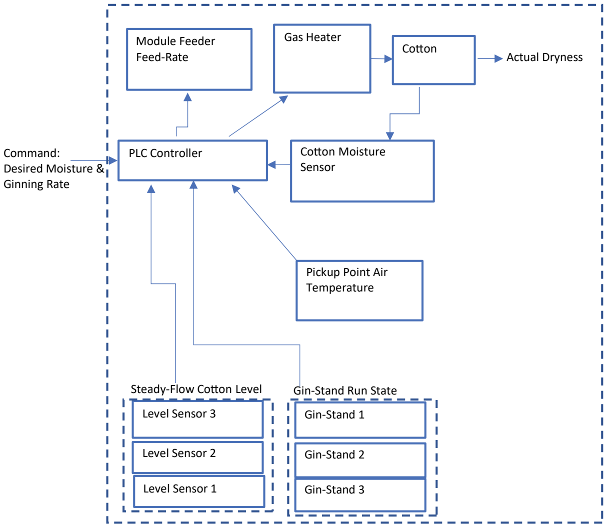

Figure 7. Multi-input multi-output feedback control system for controlling the cotton moisture and seed cotton mass flow. The PLC monitors multiple process states and adjusts the module feeder feed rate and the drying system temperature based upon the level of seed cotton in the steady flow, the number of operational gin stands, and the moisture content of the cotton.

SUMMARY

Closed-loop control systems are the heart of today's modern processing plants. These systems utilize a computer (PLC) to measure a variety of inputs and then act upon this information to optimally adjust output actuators that in turn control the plant into desired operational states to achieved production objectives and maintain high quality of output products.

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